PROJECT OVERVIEW

1 Introduction

Following the CD0 approval (approval of mission need) of the “National Synchrotron Light Source II” (NSLS-II) during August 2005, Brookhaven National Laboratory prepared a conceptual design for a world-class user facility for scientific research using synchrotron radiation. DOE SC review of the preliminary baseline in December 2006 led to the subsequent CD1 approval (approval of alternative selection and cost range). This report is the documentation of the preliminary design work for the NSLS-II facility. The preliminary design of the Accelerator Systems (Part 1) was developed mostly based of the Conceptual Design Report, except for the Booster design, which was changed from in-storage-ring tunnel configuration to in-external-tunnel configuration. The design of beamlines (Part 2) is based on designs developed by engineering firms in accordance with the specification provided by the Project. The conventional facility design (Part 3) is the Title 1 preliminary design by the AE firm that met the NSLS-II requirements. Last and very important, Part 4 documents the ES&H design and considerations related to this preliminary design.

The NSLS-II performance goals are motivated by the recognition that major advances in many important technology problems will require scientific breakthroughs in developing new materials with advanced properties. Achieving this will require the development of new tools that will enable the characterization of the atomic and electronic structure, chemical composition, and magnetic properties of materials, at nanoscale resolution. These tools must be nondestructive, to image and characterize buried structures and interfaces, and they must operate in a wide range of temperatures and harsh environments.

The NSLS-II facility will provide ultra high brightness and flux and exceptional beam stability. It will also provide advanced insertion devices, optics, detectors, and robotics, and a suite of scientific instruments designed to maximize the scientific output of the facility. Together these will enable the study of material properties and functions with a spatial resolution of ~1 nm, an energy resolution of ~0.1 meV, and the ultra high sensitivity required to perform spectroscopy on a single atom.

In order to meet this need, NSLS-II has been designed to provide world-leading brightness and flux and exceptional beam stability. The brightness is defined as the number of photons emitted per second, per photon energy bandwidth, per solid angle, and per unit source size. Brightness is important because it determines how efficiently an intense flux of photons can be refocused to a small spot size and a small divergence. It scales as the ring current and the number of total periods of the undulator field (both of which contribute linearly to the total flux), as well as being inversely proportional to the horizontal and vertical emittances (the product of beam size and divergence) of the electron beam. Raising the current in the storage ring to obtain even brighter beams is ultimately limited by beam-driven, collective instabilities in the accelerator. Thus, to maximize the brightness, the horizontal and vertical emittances must be made as small as possible.

With the concept of using damping wigglers, low-field bending magnets, and a large number of lattice cells to achieve ultra small emittance, the performance of NSLS-II will be nearly at the ultimate limit of storage ring light sources, set by the intrinsic properties of the synchrotron radiation process. The facility will produce x-rays more than 10,000 times brighter than those produced at NSLS today. The facility, with various insertion devices, including three-pole-wigglers and low-field dipole radiations, has the capability of covering a broad range of radiation spectra, from hard x-ray to far infra-red. The superlative character and combination of capabilities will have broad impact on a wide range of disciplines and scientific initiatives in the coming decades, including new studies of small crystals in structural biology, a wide range of nanometer-resolution probes for nanoscience, coherent imaging of the structure and dynamics of disordered materials, greatly increased applicability of inelastic x-ray scattering, and properties of materials under extreme conditions.

Commissioned in 1982, the existing National Synchrotron Light Source (NSLS) provides essential scientific tools for 2,300 scientists per year from more than 400 academic, industrial, and government institutions. Their myriad research programs produce about 800 publications per year, with more than 130 appearing in premier journals. It was designed in the 1970s and is now in its third decade of service. It has been continually upgraded over the years, with the brightness increasing fully five orders of magnitude. However, it has reached the theoretical limits of performance given its small circumference and small periodicity, and only a small number of insertion devices are possible. For the productivity of the large NSLS user community to continue and even increase, and in order to tackle the "grand challenge" problems of tomorrow, it is essential that NSLS be upgraded to provide much higher average brightness and higher flux.

The combination of brightness, flux, and stability of NSLS-II will provide the world's finest capabilities for x-ray imaging. NSLS-II will enable the study of materials with ~1 nanometer (nm) spatial resolution and with ~0.1 milli-electron volt (meV) energy resolution. It will be possible to focus both soft and hard x-rays to a spatial resolution of ~1 nm and to perform spectroscopy on a single atom. With the development of novel "lens-less" imaging, it will be possible to capture x-ray images with a spatial resolution of ~1 nm. This resolution and sensitivity is unprecedented in x-ray imaging. If there is any doubt that this is needed for our future energy security, one only need remember that all the elementary steps of energy conversion (charge transfer, molecular rearrangement, and chemical reactions), both for fossil fuels and for critical renewable energy sources, take place on the nanoscale, and many of these steps involve a combination of complex physical, chemical, and often biological, transformations.

The unique characteristics of NSLS-II will enable exploration of the scientific challenges faced in developing new materials with advanced properties. These challenges include exploringthe correlation between nanoscale structure and function— investigatingthe profound effects of confinement, finite size, and proximity; the mechanisms of molecular self-assembly, which produces exquisite molecular structures in both the living and nonliving worlds; and the science of emergent behavior, one of the grand scientific challenges.

2 Scope

The project scope includes the design, construction, installation, and commissioning of the accelerator hardware, civil construction, and central facilities required to produce a new synchrotron light source. It includes a highly optimized electron storage ring, full energy injector, experimental beamlines and optics, and appropriate support equipment, all housed in a new building. Specifically, the main scope elements include:

- an electron gun and a short linac, where an electron beam is generated and accelerated to 200 meV
- the transport system to the booster
- the booster ring, where the electrons from the linac are accelerated to 3 GeV for injection into the main storage ring
- the transport system to the main storage ring
- the main storage ring, where a 500 mA current of electrons is stored at an energy of 3 GeV and sent through insertion devices and bend magnets to produce synchrotron radiation
- a suite of initial beamlines and supporting instrumentation
- the ring building, operations center, auxiliary lab office buildings, and mechanical equipment rooms, comprising the conventional facilities and supporting utility infrastructure

3 Capabilities

NSLS-II is a synchrotron with a highly optimized design that will be capable of producing world-leading levels of brightness and flux and small beams, over a very broad energy range, extending from the far IR to the very hard x-ray region. The main performance characteristics are given in Table 1.

Table 1 Main Performance goals of the NSLS-II Storage Ring.

Electron energy [GeV]	3.0
Stored current [mA]	500
Stability of average current [%]	<1
Horizontal emittance [nm-rad]: Baseline	1.0
Horizontal emittance [nm-rad]: Fully Built-out	0.6
Vertical emittance [nm-rad]	0.008
Average brightness [ph/s/0.1%bw/mm^2/mrad^2] in the 2keV to 10keV photon energy range	$>10^{21}$
Average flux [ph/s/0.1%bw] in the 2keV to 10keV photon energy range	$>10^{16}$
Horizontal electron beam size [μm]: Baseline	42
Horizontal electron beam size [μm]: Fully Built-out	32
Horizontal electron beam divergence [μrad]: Baseline	22
Horizontal electron beam divergence [μrad]: fully Built-out	16
Vertical electron beam size [μm]	3.2
Vertical electron beam divergence [μrad]	2.5
Stability of electron beam in position, size, and direction [%] of beam size or divergence	<10
Number of straight sections for insertion devices	27
Number of bend magnet sources	30

4 Work Breakdown Structure

The NSLS-II project has been organized into a Work Breakdown Structure (WBS). The WBS contains a complete definition of the project’s scope and forms the basis for planning, executing, and controlling project activities. The Project WBS is shown in Figure 1. Elements are defined as specific systems/deliverables (WBS 1.3–1.5), project management (WBS 1.1), research and development (WBS 1.2) or pre-operations (WBS 1.6), consistent with discrete increments of project work and the planned method of accomplishment.

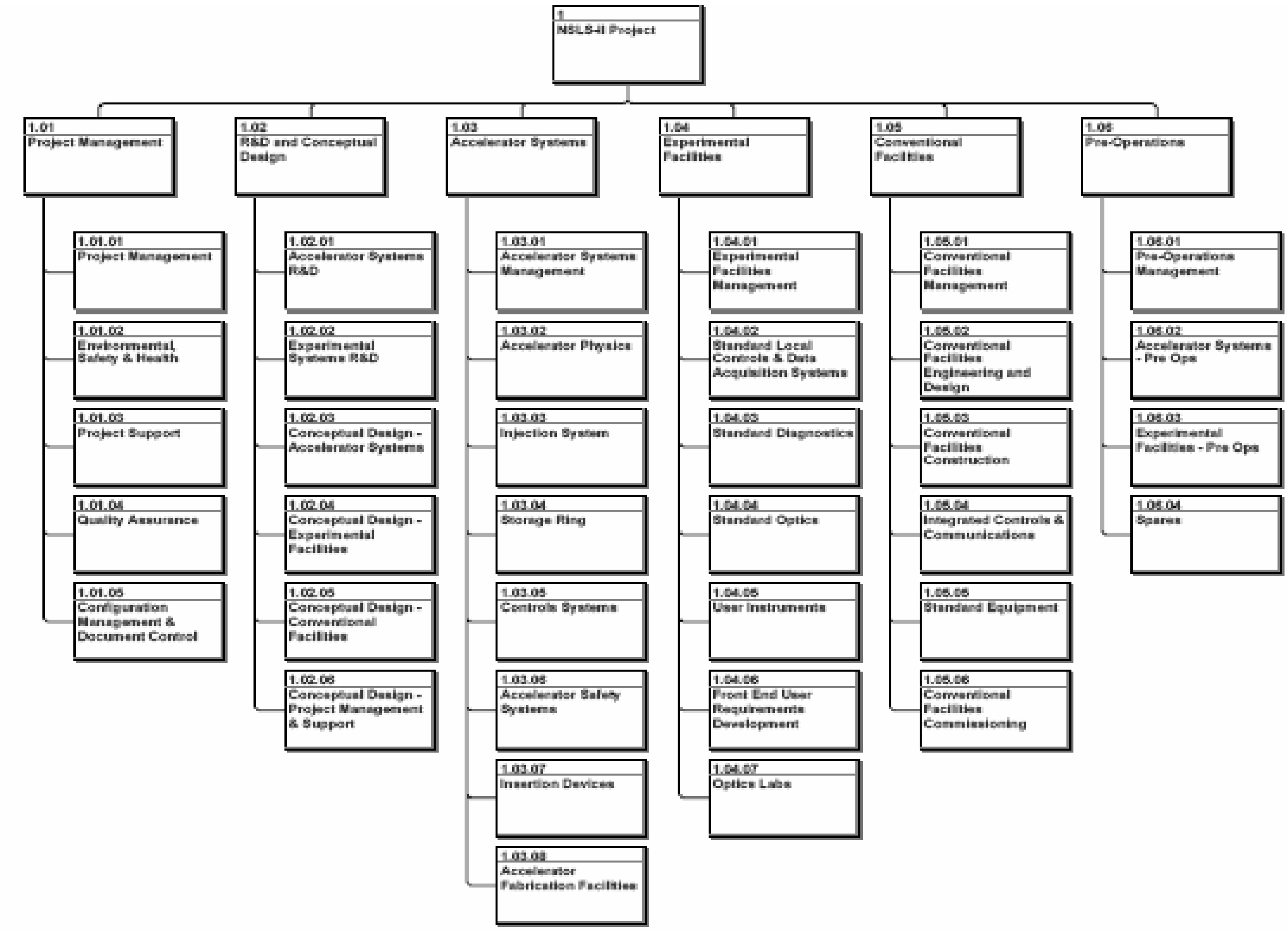

Figure 1 Work breakdown structure for the NSLS-II project:

1.01 Project Management – Project Office administrative and management activities that integrate across the entire project (management, regulatory compliance, quality assurance, safety, project controls, etc.)

1.02 Research and Development – R&D activities as necessary to support the delivery of project objectives

1.03 Accelerator Systems – All phases of design, procurement, installation, and commissioning of the accelerator systems

1.04 Experimental Facilities – All phases of design, procurement, installation, and commissioning of the suite of beamlines and instruments included in the project scope

1.05 Conventional Facilities – All phases of design, procurement, installation, and commissioning of the conventional facilities including preparation of the site and provision of all utility systems

1.06 Pre-Operations – Materials, equipment, services, etc. for integrated testing and commissioning

5 Cost and Schedule

The Total Estimated Cost (TEC) of NSLS-II is $785.4M. The Total Project Cost (TPC) is $896.2M. The schedule for construction will lead to start of operations in FY2014.

A preliminary high-level summary of the cost of the NSLS-II project, at the second level of the work breakdown structure, is given in Table 2.

Table 2 Level 2 Cost Breakout for the NSLS-II Project (fully burdened).

NSLS-II Level 2 Cost Element	Cost (AY $M)
1.1 Project Management and Support	52.5
1.3 Accelerator Systems	239.5
1.4 Experimental Facilities (includes contingency)	69.3
1.5 Conventional Facilities	240.8
Contingency (35% of TEC cost elements excl. Exp. Facilities)	183.3
NSLS-II Total Estimate Cost (TEC)	785.4
1.2 R&D	60.6
1.8 Pre-operations	50.2
Total Other Project Costs	110.8
NSLS-II Total Project Costs (TPC)	896.2

A preliminary Level 0 milestone schedule to construct NSLS-II is shown in Table 3.

Table 3 Preliminary Level 0 Milestone Schedule.

Major Milestone Events		Preliminary Schedule
CD-0	(Approve Mission Need)	4th Qtr, FY2005
CD-1	(Approve Alternative Selection and Cost Range)	3rd Qtr, FY2007
CD-2	(Approve Performance Baseline)	4th Qtr, FY2008
CD-3	(Approve Start of Construction)	2nd Qtr, FY2009
BOD of Experimental Floor Space		2nd Qtr, FY2012
CD-4	(Approve Start of Operations)	3rd Qtr, FY2015

6 Acquisition Strategy

The acquisition strategy relies on Brookhaven Science Associates (BSA), the Department of Energy Managing and Operating (M&O) contractor for Brookhaven National Laboratory, to directly manage the NSLS-II acquisition. The design, fabrication, assembly, installation, testing, and commissioning for the NSLS-II project will be largely performed by the BNL/NSLS-II scientific and technical staff. Much of the subcontracted work to be performed for NSLS-II consists of hardware fabrication and conventional facilities construction.